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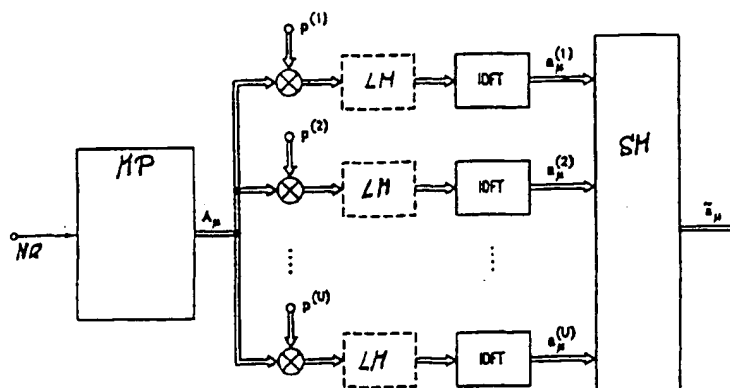
(57) Abstract

A major problem in multicarrier transmission procedures consists in the very high crest factor of the transmit signal. It is the object of the invention to provide a method, whereby a definite predetermined reduction of signal peaks is achieved. This is achieved by generating, in addition to the information to be transmitted, several alternative sequences, by means of determined, reversible, unambiguous representations. From these alternatives a favorable sequence is selected and transmitted. The receiver is in a position to regenerate the original information from said receiving signal through the inversion of the performed representation.

REDUCTION OF THE PEAK TO AVERAGE POWER RATIO IN MULTICARRIER MODULATION SYSTEM

The invention relates to a method and a device for reducing the signal peak-to-average power ratio of the transmit signal in digital transmission procedures.

A system for multicarrier transmission is known from the prior art according to EP 702 466 A2, whereby the data stream to be transmitted is partitioned into several parallel sub-channels, which are transmitted into frequency multiplexing. The crest factor, which is defined as the ratio of the peak voltage to the average voltage, is thereby reduced by using a first set of four symmetrically arranged sub-channel pairs for encoding the information bits, wherein the resulting phase vector for each pair of sub-channel pairs contained in the second set is vertical to the resulting phase vector of one of the pairs in the first set of sub-channels. However, the reduction of the peak value is here too ineffective and too low.

Moreover, systems are known in the field of digital telecommunication transmission enabling a high-rated data transmission. One technique becoming increasingly important in this respect is the multicarrier transmission, which is known by the name Orthogonal Frequency Division Multiplexing (OFDM), Discrete Multi Tone (DMT) and

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<u>M</u>ulti <u>C</u>arrier <u>M</u>odulation (MCM). In multicarrier transmission the data stream to be transmitted is partitioned into many parallel sub-channels, which are preferably transmitted in frequency multiplexing. Besides, however, other multiplexing techniques can also be applied. It is characteristic in each case, that the available transmission medium is decomposed into many parallel sub-channels, also called carriers, which can be used independent of each other. Preferably, <u>P</u>hase <u>S</u>hift Keying (PSK) or <u>Q</u>uadrature <u>A</u>mplitude <u>M</u>odulation (QAM) modulation methods are applied in the individual sub-channels. A realization of this principle being favorable in terms of expenditure consists in the application of the fast fourier transform (FFT). By introducing a so-called guard interval, whereby a block of transmit symbols is expanded by partial cyclic repetition, linear distortions of the transmission medium, or multipath transmission respectively, merely result in independent weighting according to rate and phase of each sub-channel. If a differential modulation is used, i.e. if the information is denoted on the difference of two consecutive symbols, no equalization in the receiver is required, since not the absolute signal but only the relative change bears the information.

A substantial disadvantage in multicarrier transmission methods is that very high power peaks can occur even in case of moderate average transmission performances. This is due to the independence of the sub-channels resulting in a possible constructive overlapping of the sub-signals. A factor for the power peaks is the so-called crest factor ς

$$\varsigma = \sqrt{\frac{\text{crest factor performance}}{\text{average performance}}}$$

which in information technology plays a decisive role in dimensioning the transmitter amplifier used. For high peak values a great maximum performance, the so-called back-off, is thereby required, resulting in the amplifiers operating with a very poor efficiency. On the other hand, the amplifiers must not be operated too close to the saturation, for the amplifying characteristic clearly deviates from the ideal linear course. If, moreover, the transmission phase is overloaded, saturation effects of the amplifier cause an out-of-band radiation, i.e. the transmit power is spread out of the

frequency band available for the transmission and disturbs possibly present transmission systems.

By a reduction of the crest value of multicarrier transmit signal on the transmit side, smaller and thus substantially inexpensive power amplifiers could be applied if the effective power to be radiated is predetermined. Multicarrier transmission methods would thereby become even more attractive.

The prior art, moreover, discloses further attempts to reduce the crest factor of multicarrier transmit signals.

The essay „Reduzierung der durch Nichtlinearitäten hervorgerufenen Außerbandstrahlung bei einem Mehrträgerverfahren" [Reduction of out-of-band radiation caused by non-linearities in multicarrier methods" by M. Pauli and H.-P. Kuchenbecker, ITG Technical Report 136 „Mobile Communication", a method is introduced, whereby the peak amplitudes are increased by subsequently processing the transmit signal. For this purpose, said peak amplitudes are searched for in a first step, and in the environment of which peak amplitudes the amplitude of the transmit signal is reduced in a „soft" manner (gradual decrease of the average power and subsequent reduction to the original value) in a second step, such that a desired peak power is not exceeded. Since this generally constitutes a non-reversible operation, the information can no longer be recovered in the receiver in an ideal manner resulting in a higher error rate. Particularly, even in an interference-free channel a faultless transmission cannot be guaranteed.

Furthermore, a large number of other attempts are known („block coding scheme for reduction of peak to mean envelope power ratio of multicarrier transmission schemes" by A. Jones, T. Wilkinson and S. Barton, Electronics Letter, December 1994, or „Reduction of peak to mean ratio of multicarrier modulation using cyclic coding" by D. Wulich, Electronics Letters, February 1996), from which it can be inferred that redundancy is introduced into the signal, mainly by using individual carriers not for data transmission purposes, but for influencing the transmission signal course. Often specially designed block codes for expressing the most favorable redundancy symbols are being applied. Partially it is attempted to

simultaneously use said codes for correcting errors. A great disadvantage in these methods is that they are mostly only suited for a very small number of carriers, which is of no interest in practical application. Also, said methods are restricted to binary or perhaps quartemary phase shift keying (PSK) in the sub-channels. For each change in the constellation of the signals or carrier occupancy, therefore, an adopted strategy of redundancy introduction is required, which results in very inflexible methods.

Another method known from the prior art („Multicarrier modulation with low peak-to-average power ratio" by M. Friese, Electronics Letters, April 1996) uses an iterative process for determining the redundant parameters. For obtaining a signal with very low peak values, however, an excessive amount of fourier transformations is necessary. Apart from the great numerical expenditure, above all the large required redundancy (up to 50%) is a major critical issue. The greatest disadvantage in practically all previously suggested attempts to provide a solution is that often only those peak amplitudes are avoided, which occur with an almost disappearing probability and can, thus, be neglected in practical operation anyway. In practice, however, it is the object to obtain a reduction of all signal peaks to a supportable extent. Also, the known methods have been strongly adapted to the symbol alphabet used, the concrete assignment of information to the signal points or the number of carriers, which makes them extremely unflexible.

It is the object of the invention to provide a method and device for digital transmission procedures, particularly by means of multicarrier modulation, whereby a recognizable reduction of the crest factor of the transmit signal is made feasible. It is particularly the object of the invention to provide a device and a method, whereby a maximum reduction of the crest factor with a minimum of additional redundancy is obtained, resulting in a reliable and significant reduction of the peak values independent of the number of carriers used in the multicarrier modulation procedure, which reduction is largely independent of the modulation procedures applied in the individual carriers and of the specific assignment of data to signal points, and which can be performed with justifiably more expenditure in the transmitter and the receiver.

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According to the invention, this object is provided by the teaching of patent claim 1 and patent claim 17.

According to patent claim 1 the information to be transmitted is modified by a pre-set number of deterministic and reversible unambiguous representation functions, whereby in addition to the original information sequence, alternative information-equivalent sequences are generated in the transmitter. After modulating the equivalent information sequences a transmit signal for the actual transmission is selected from the information-equivalent transmit signals, which transmit signal is favorable in view of the occurring maximum signal amplitudes. In knowledge of the currently applied deterministic representation the original information can be reproduced.

Thus, the method according to the invention allows in an advantageous manner a clear reduction of the signal peak values in multicarrier modulation and thereby enable the operation of transmit amplifiers with a clearly smaller back-off with a comparable out-of-band radiation. The power components to be applied on the transmit side hereby become less expensive and can more efficiently be operated in one working point, which has a positive effect on the operation time of devices with no intermediate ac power supply, especially in mobile communication application.

Moreover, the method works with a justifiable higher expenditure in the transmitter and receiver, since often a sufficiently high reduction of the peak values can already be achieved with a few alternative information sequences. The invention works in all embodiments, independent of the concretely underlying modulation procedure in the individual carriers, the used signal alphabets, the specific assignment or the used number of carriers.

Further advantageous developments can be inferred from the subclaims.

A particularly advantageous development of the method consists in communicating the representation regulation performed with the transmitted signal sequence in the concrete case to the receiver via additional side information in a suitable way.

Alternatively, the representation regulation can be regenerated by the receiver itself by means of suitable measures.

It is further advantageous, that only a fraction of additional redundancy is introduced into the signal. By the reduced dynamics of the occurring signal values, also the components for the digital/analog conversion in the transmitter and for the analog/digital conversion in the receiver can be reduced in the resolution, again leading to cost savings with regard to the devices.

In the following the invention is explained in more detail by means of figures and embodiment:

Fig. 1   shows a representation of the inventive device for reducing the peak value problem in multicarrier methods,

Fig. 2   shows a representation of a partition of the carriers on the subblocks for $V = 3$,

Fig. 3   shows a representation of the inventive device for restricting the peak value problem in multicarrier methods,

Fig. 4   shows an example of an advantageous partition of the carriers on subblocks with differential modulation in frequency direction for $V = 3$.

In the explained embodiment, different methods for generating information-equivalent information are applied.

In the following the invention is explained in more detail by means of figure 1 and a first embodiment.

Multicarrier transmission methods are commonly efficiently realized by representing blocks of the information NR supplied to the modulator by so-called mapping MB on a block (vector) A_μ of length N consisting of carrier values $A_{\mu,\nu}$, $\nu = 0,...,N - 1$. Said mapping comprises a serial/parallel conversion of the information NR and the representation of information NR. The respective carrier values, i.e. the signal points, are selected from a discrete signal alphabet A as function of the respective

information to be transmitted. In general, the signal points are complex numbers. A transmission sequence $a_{\mu,\rho}$ with $\rho = 0,...,N-1$ being part of said block consisting of carrier values, which in the following is designated by carrier constellation A_μ, is obtained by Inverse Discrete Fourier Transformation IDFT of A_μ. The transmission sequence of complex values $a_{\mu,\rho}$ is favorably combined to form a vector a_μ. In addition, however, any other kind of transformation can be applied, e.g. the Walsh-Hadamard transformation, a discrete cosine transformation or the Karhunen-Loeve transformation. Part thereof is also a transmit pulse shaping with the common PAM transmission, a single-carrier procedure resulting for N = 1, a transformation of a time-discrete signal into a time-continuous transmit signal. Also combinations of the mentioned transformations and a pulse shaping are possible.

In the first advantageous embodiment of the inventive method according to figure 1, U vectors $P^u = P^u{}_0$, $P^u{}_1$, ... , $P^u{}_{N-1}$, u = 1 different from each other, comprising complex values $P_v{}^{(u)}$ and $|P_v{}^{(u)}|$ = const., v = 0,..., N-1 are stipulated between transmitter and receiver first. Alternatively, said vectors can also algorithmically be produced in transmitter and receiver according to the same standing predetermined regulation. Also, each of the modification vectors $P^{(u)}$ can be stipulated anew from one block to the consecutive one. The product $A_{\mu,v} P_v{}^{(u)}$ is then formed component-wise on the transmit side, and the pertinent time signals are calculated from the thereby formed blocks by means of the used transformation IDFT. From said U possibilities a favorable transmit signal $\tilde{a}_\mu$ is finally selected for the actual transmission by using an estimating means SM. In knowledge of the currently used vector $P^{(u)}$ the information vector A_μ and thus the information contained therein, can be recovered at receiving side through division with $P^{(u)}$.

Additionally, (as indicated by the interrupted lines) a differential modulation DM can be applied to the product $A_{\mu,v} \cdot P_v{}^{(u)}$, with the result that the used transmit channel needs not be estimated.
The selection of $P_v{}^{(u)}$ from the set

$$P_v^* \in \{\pm 1, \pm j\}$$

with an absolute value $|P_v^{(u)}| = 1$, for example, proves to be advantageous. The multiplication with a complex value results in a phase rotation, whereby the amplitude remains unmodified by the selection of this absolute value.

A possible development of the invention consists in communicating the number u of the modification vector $P^{(u)}$ as side information in the transmit signal itself to the receiver. This would be possible, for example, by reserving individual carriers $A_{\mu\nu}$, which do not carry any useful information.

A second development is to be seen in that the number of $P^{(u)}$ is not explicitly communicated to the receiver, but that the receiver itself regenerates the number of the actually used vector $P^{(u)}$ for the inversion of the modification. In this respect an encoding for correcting errors, which is present anyway, would have to be applied for this task as well. For this purpose U decoders estimate vector A_μ, whereby said U decoders each assume a possible vector $P^{(u)}$. Finally that estimated value is used for the further processing, which value shows the greatest probability.

In case of unknown or time-variant channels, as are used, for example, in mobile communications, the information is favorably not absolutely represented in the signal, but is differentially represented, i.e. in the modification of consecutive symbols $A_{\mu\nu}$. This merely requires an integration (addition) on the transmit side following the multiplication with $P^{(u)}$, since $A_{\mu\nu} \cdot P^{(u)}$ now constitute the increments. At receiving side, prior to a possibly present decoder and prior to the inversion of the modification, this step is undone by differentiation.

In the following another embodiment is explained by means figures 2 and 3.

Another advantageous development of the invention is one to be favorably implemented for a linear signal transformation. An information NR is, as was explained in the preceding embodiment, represented by so-called mapping MP. In said embodiment, a partition of carriers A_μ occupied in the respective multicarrier modulation method into V subblocks takes place, each of which pair-wise occupy

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disjoint carrier positions with the corresponding amplitude values from the respective totality A_μ of the carrier values, whereby the total number of carrier positions adopted in this way in the respective subblocks $A_\mu^{(v)}$ is arbitrary. All carrier positions of the respectively regarded subblock being accommodated in other subblocks are occupied by zero. The partition of the individual carriers to the respective blocks is also arbitrary. A possible partition is depicted in figure 2. After the partitioning each carrier position from A_μ is represented in exactly one subblock $A_\mu^{(v)}$.

The thereby obtained subblocks $A_\mu^{(v)}$ of carriers are individually transferred in so-called partial transmit sequences $a_\mu^{(v)}$ by a number V of linear transformations IDFT (to be put in parallel by the corresponding hardware). Based on said sequences a targeted optimizing combination of the partial transmit sequences can be performed in a peak value optimization SO by means of a process suitable for this purpose, whereby only a small number of parameters b_v, with $b_v = \mathrm{const.} \cdot e^{j\Phi_v}$, $\Phi_v \in [0, 2\pi]$ rotation (rotational expansion) of the complex signal is to be determined, the effect of which on the transmit signal can directly be inferred from the intermediate results $a_\mu^{(v)}$. The ideal result of the optimization with the optimum factors is

$$(\hat{b}_1, ..., \hat{b}_V) = \operatorname*{argmin}_{(b_1, ..., b_V)} \left(\max_{\rho=0,...,N-1} \left| \sum_{v=1}^{V} b_v \, a_{\mu,\rho}^{(v)} \right| \right), \; |b_v| = \mathrm{const.} \qquad v = 1,...,V \quad (1)$$

transmit signal sequence

$$a_\mu = \sum_{v=1}^{V} \hat{b}_v \, a_\mu^{(v)} \qquad\qquad\qquad (2)$$

which, among all alternative transmit sequences, has the lowest peak value. According to the invention, however, other transmit sequences $\bar{a}_\mu$ too can be generated and transmitted, which have a crest factor being sufficiently small for the application.

The inventive process according to the embodiment is applied as follows. For example, $b_1 = 1$ can be set, which means that one of the formed subblocks is transmitted always unrotatedly. Said block can, among others, comprise the carriers

which for various reasons are to be transmitted with a distinct fixed phase position, such as pilot carriers for channel estimation. In case of a coherent or in time direction differentially coherent demodulation said carriers can, for example, also transmit the side information required in this respect. Thus, only V - 1 phase positions are to be determined through optimization and to be transmitted to the receiver.

The side information can, for example, be directly transmitted with the modified multicarrier signal within the one unrotated subblock. Said information can thereby be protected by an efficient code and/or the information can be transmitted on carriers specifically reserved for this purpose with a low-grade and thus efficient modulation. The side information on the unrotated individual carriers, which can be arbitrarily spread over the frequency domain, can thus safely be obtained without any additional knowledge and immediately be used for demodulating the potentially rotated subblocks.

The number of possible rotational angles for the blocks should not be too large, in order not to allow the quantity of bits required for the transmission of the side information to increase unnecessarily. For reasons of facilitation one can restrict oneself to the four factors $b_v \in \{\pm 1, \pm j\}$ when implementing the attempt for a solution, whereby 2 (V-1) bits side information are to be transmitted per multicarrier signal sequence. Moreover, real multiplications no longer occur in respect of the implementing expenditure when combining the partial transmit signals to form the final transmit signal. The operations required for this purpose can then be easily performed by changing real and imaginary part as well as by additions and subtractions.

A restriction to four possible factors enables a sufficiently good reduction of the peak value, and a further increase in the possibilities does not yield any additional gains justifying the expenditure. The (sub) optimized are here determined by

$$(\hat{b}_1,...,\hat{b}_V) = \underset{(b_1,...,b_V)}{\arg\min} \left(\max_{\rho=0,...,N-1} \sum_{v=1}^{V} \left| b_v \ a_{\mu,\rho}^{(v)} \right| \right), b_v \in \{\pm 1, \pm j\} \ v = 1,...,V \qquad (3)$$

In the device according to the embodiment, for example, specifically tuned transformation algorithms (e.g. for IDFT) can be realized, which make use of a major part of the input values in the carrier subblocks $A_\mu^{(v)}$ to be transformed being zero, whereby the increased expenditure through multiple transformations in the inventive method especially with a suitable subblock partition is reduced anew.

A very favorable embodiment of the method consists in that the information to be transmitted is each differentially modulated in a block-wise manner. This means that each block is differentially modulated from carrier to carrier for itself, i.e. in frequency direction. For this purpose, in principle all signal alphabets can be used, which can be modulated differentially, such as M-DPSK (M-ary Differential Phase-Shift Keying) or M-DAPSK (M-ary Differential Amplitude and Phase-Shift-Keying), processes obtaining a higher spectral efficiency. A transmission of explicit side information is no longer required in this scheme. Merely the block partition must be specified and known in both the transmitter and the receiver.

In connection with a differential modulation in frequency direction, different block partitions are possible, which in view of the present channel permit a reliable digital transmission. As is shown in figure 4 for V=3, for example, the individual blocks can be engaged in a comb-like manner. For minimal redundancy the block partition in the present embodiment of the method can, however, also be selected that adjacent, gap-free carriers are combined in one subblock. Thus, each of the V blocks only has one redundant reference carrier, which is left unmodulated as fixing point first, and . can thus be interpreted as signal-shaping redundancy.

As desired, the differentially introduced information within a subblock remains untouched through the common rotation of all individual carriers in the subblock and can thereby be demodulated subblock-wise in the receiver without any side information.
Due to the asymmetry of the expenditure a method specialized in this way could ideally be applied in broadcast application, since the receivers nearly exactly correspond to the receiver with unprocessed transmit signal in view of their complexity, and are thereby do not become more expensive through the dynamics-reducing measures.

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Patent Claims

1. Method for reducing the crest factor in digital transmission procedures, wherein digital information is modified on the transmit side by deterministic and reversible unambiguous representation regulations, whereby alternative, information-equivalent sequences are generated, from which a sequence favorable in respect of a peak value of a pertinent transmit signal is selected, which sequence is used for the transmission.

2. Method according to claim 1, wherein the signal being transmitted is generated from the original information signal through transformation.

3. Method according to clam 2, wherein the transformation generates a multicarrier transmission procedure.

4. Method according to claim 2, wherein the transformation generates a bandwith-efficient, time-continuous signal from a time-discrete signal.

5. Method according to claim 1, 3 or 4, wherein the alternative, information-equivalent sequences are formed from carrier values $A_{\mu\nu}$, $\mu = 0,...,N\text{-}1$, by multiplication with arbitrarily selective values $P_\nu^{(u)}$, $u=1,...,U$.

6. Method according to claim 5, wherein the values $P_\nu^{(u)}$ are firmly stipulated between transmitter and receiver.

7. Method according to claim 6, wherein the values $P_\nu^{(u)}$ are separately determined for themselves, each according to the same pre-set regulation in the transmitter and receiver.

8. Method according to claim 5, 6 or 7, wherein $P_\nu^{(u)}$ is a complex number, the absolute value of which is $|P_\nu^{(u)}|$ equal to 1.

9. Method according to one of claims 5 to 8, wherein the number u of values $P_v^{(u)}$ is communicated to the receiver as side information.

10. Method according to one of claims 5 to 9, wherein the receiver derives the number u of values $P_v^{(u)}$ from the receiving sequence.

11. Method according to one of claims 5 to 10, wherein the information is differentially represented in the signal, and the modified carriers $A_{\mu,v} P_v^{(u)}$ thus each constitute the information increments from which the finally to be transmitted information sequence is gained by integration.

12. Method according to one of claims 1 to 4, wherein a carrier block A_μ is partitioned into V subblocks $A_\mu^{(v)}$ v=1, which are separately transferred into partial transmit sequences, which are finally combined to form an information-equivalent transmit sequence in an optimizing manner by means of arbitrary factors $b_1,...,b_v$.

13. Method according to claim 12, wherein $b_1,...,b_v$ has a complex value, the absolute value of which is $|b_1|=..=|b_v|=1$.

14. Method according to claim 12 or 13, wherein the factors $b_1,...,b_v$ of the subblocks are communicated to the receiver as side information in a suitable representation.

15. Method according to claim 12 or 13, wherein the factors $b_1,...,b_v$ in the receiver are solely derived from the receiving frequency.

16. Method according to claim 12 or 13, wherein the information is differentially and not absolutely represented in the signal in frequency direction, and the subblock partition is selected for this purpose in a suitable manner.

17. Device for reducing the crest factor in digital transmission procedures, characterized by

a representation device (MP) for representing digital information (NR) on carrier values (A_μ),

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means for multiplying the carrier values (A_u) with arbitrarily eligible values ($P_v^{(u)}$),

means (IDFT) for transforming the carrier values into alternative information-equivalent sequences, and

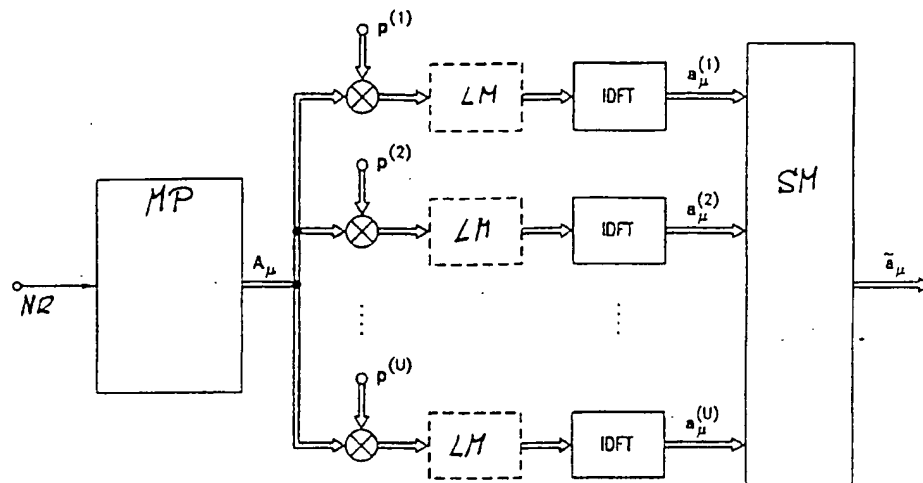means for selecting a sequence favorable in view of the peak value, which is used for the transmission.
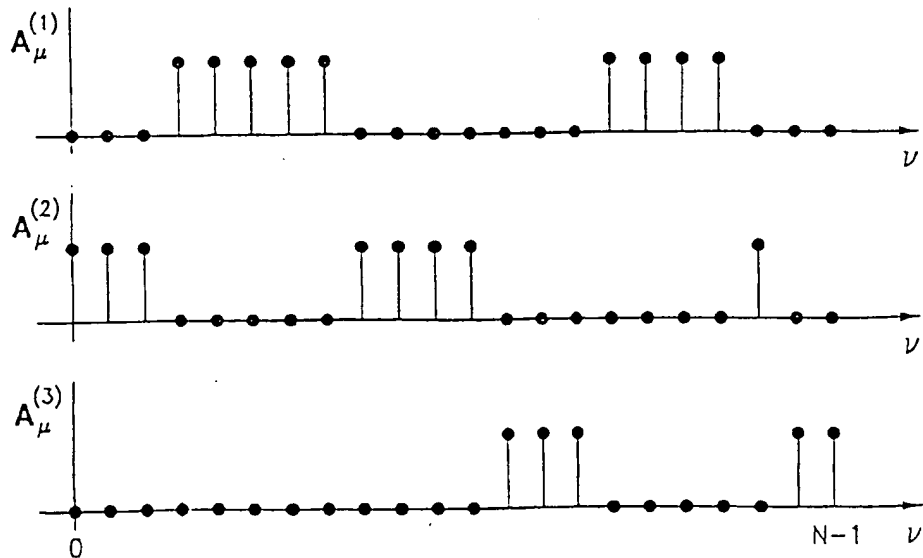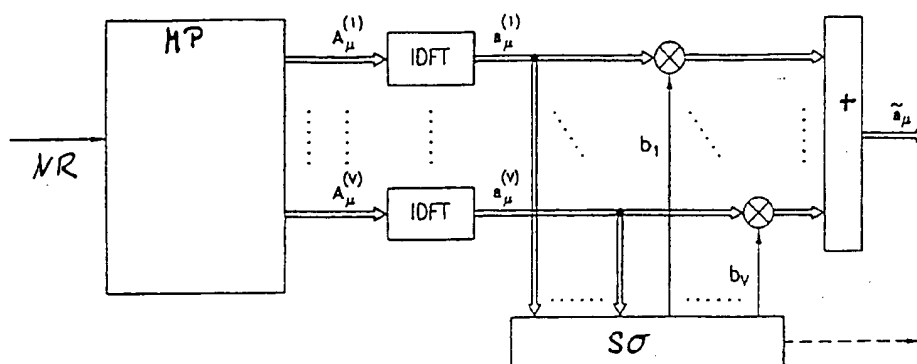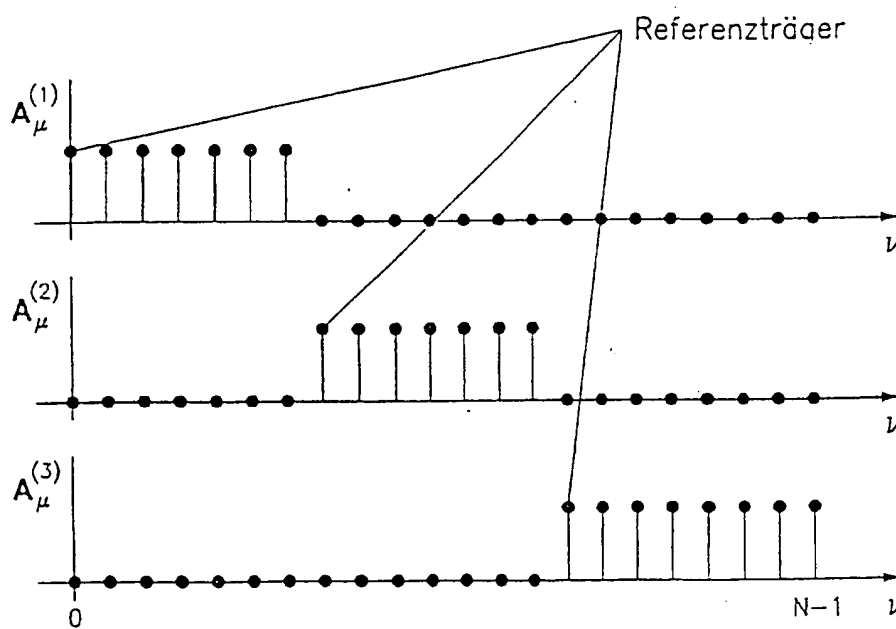
Fig. 1

Fig. 2

Fig. 3

Fig. 4

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6   H04L27/26

According to International Patent Classification(IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6   H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category [*]	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No
X	ZOGAKIS, ASLANIS, CIOFFI: "A coded and shaped discrete multitone system" IEEE TRANSACTIONS ON COMMUNICATIONS., vol. 43, no. 12, December 1995, NEW YORK, US, pages 2941-2949, XP000545027 see page 2941, right-hand column, paragraph 1 see page 2946, left-hand column, paragraph 2 --- -/--	1-11,17

☒ Further documents are listed in the continuation of box C.   ☒ Patent family members are listed in annex.

[*] Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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Date of the actual completion of the international search	Date of mailing of the international search report
23 January 1998	29/01/1998

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl. Fax: (+31-70) 340-3016	Scriven, P

Form PCT/ISA/210 (second sheet) (July 1992)

page 1 of 2

INTERNATIONAL SEARCH REPORT

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No
X	VAN EETVELT, SHEPHERD, BARTON: "The distribution of peak factor in QPSK multi-carrier modulation" WIRELESS PERSONAL COMMUNICATIONS., vol. 2, no. 1, January 1995, KLUWER ACADEMIC PUBLISHERS, NL, pages 87-96, XP000589613 see page 89, paragraph 2 - paragraph 3 see page 92, paragraph 4 see page 93, paragraph 4	1-11,17
A	NARAHASHI, KUMAGAI, NOJIMA: "Minimising peak-to-average power ratio of multitone signals using steepest descent method" ELECTRONICS LETTERS., vol. 31, no. 18, 31 August 1995, ENAGE, GB, pages 1552-1554, XP000530948 see page 1553, left-hand column, paragraph 2; figure 2	1-17
A	JONES, WILKINSON: "Combined coding for error control and increased robustness to system nonlinearities in OFDM" 1996 IEEE VEHICULAR TECHNOLOGY CONFERENCE, 28 April 1996 - 1 May 1996, NEW YORK, US, pages 904-908, XP000593105 see page 904, left-hand column, paragraph 2	1-17
X,P	EP 0 735 731 A (VICTOR COMPANY OF JAPAN) 2 October 1996 see abstract; figures 4,6,9-12 see column 2, line 56 - column 3, line 7	1-17
A	WO 96 13918 A (AIRNET COMMUNICATIONS) 9 May 1996 see abstract; figure 1 see page 3, line 15 - line 20 see page 5, line 1 - line 4	1-17
A	PAULI, KUCHENBECKER: "Reduzierung der durch Nichtlinearitäten hervorgerufenen Außerbandstrahlung bei einem Mehrträgerverfahren" NTG FACHBERICHTE, no. 135, January 1995, DE, pages 467-475, XP000565905 see page 471	1-17

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0735731 A	02-10-96	JP 8274748 A JP 9107345 A	18-10-96 22-04-97
WO 9613918 A	09-05-96	AU 4017795 A	23-05-96

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